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Assessing the State of Digital Skills in the U.S. Economy

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An increasingly digitalized global economy requires ever-more digitally skilled workforces for nations to remain productive. Unfortunately, domestic and international assessments of digital skills show the United States is lagging its competitors.

KEY TAKEAWAYS

- According to the OECD, fully one-third of working-age Americans possess even limited digital skills. One in six are unable to use email, web search, or other basic online tools.
- The United States ranks just 29th out of 100 countries for the digital acumen of its workforce in business, technology, and data science, according to Coursera.
- This comes against a backdrop of increasing digital skills requirements for many U.S. occupations. Brookings found that whereas only 44 percent of U.S. jobs required medium-high digital skill levels in 2002, 70 percent did by 2016.
- Digital skills are critical to higher wages: Jobs that incorporate higher levels of digital content pay more—in fact, for every 10 percent increase in ICT-task intensity, the average U.S. worker's salary increases 4 percent.
- The United States needs to increase its number of computer science graduates and concentrate particularly on women, who represented 37 percent of U.S. computer scientists in 1995, but just 24 percent today.
- The United States needs to significantly increase its investment in workforce training, including for digital skills. As a share of GDP, the federal government now invests less than half as much in such programs as it did 30 years ago.
- With corporate investment in workforce training also falling by 30 percent as a share of GDP from 1999 to 2015, Congress should expand Section 127 tuition credits.

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EXECUTIVE SUMMARY

The global economy is increasingly digitalized. Oxford Economics estimated that in 2016 the digital economy accounted for 22.5 percent of global gross domestic product (GDP).[1] Going forward, analysts at the research firm IDC have estimated that as much as 60 percent of global GDP will be digitalized (meaning largely impacted by the introduction of digital tools) by 2022.[2] Countries that wish to successfully compete in the global digital economy must cultivate workforces possessing the requisite digital skills so that industries, enterprises, and even individuals can thrive in the digital environment. This report explores the state of digital skills across the U.S. economy, examining what they are, why they matter, the current extent of workforce digitalization, and how the United States fares in international digital skills comparisons. It concludes by providing a brief overview of some of the best practices and programs being introduced by nonprofit, academic, and corporate organizations to deepen the U.S. digital skills base and suggesting policy recommendations to further foster U.S. digital skills development.

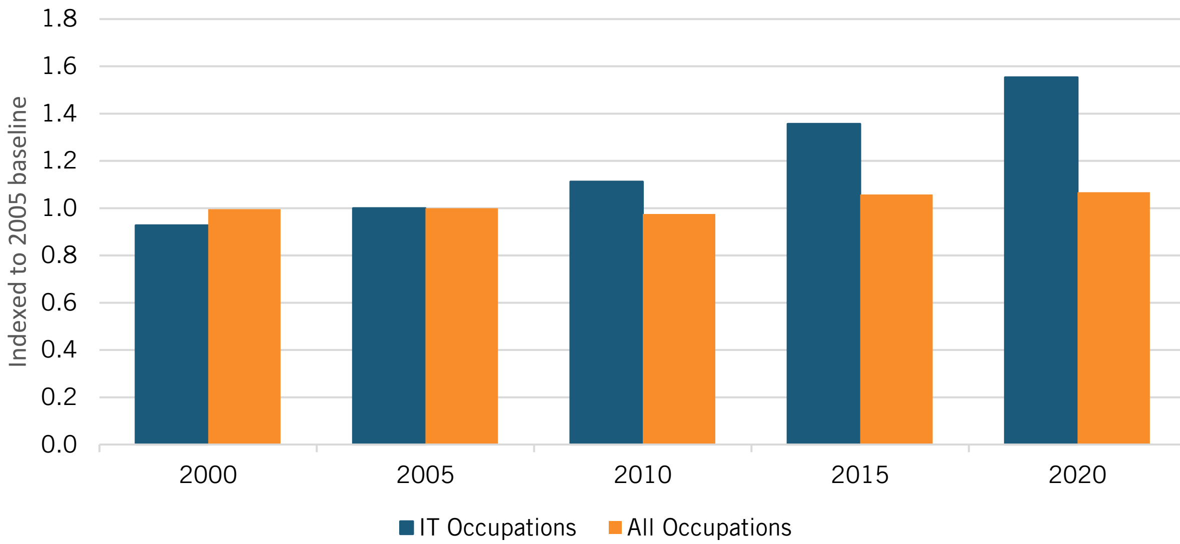
WHAT ARE DIGITAL SKILLS AND WHY DO THEY MATTER?

The globalization of the digital economy profoundly impacts every industry. For instance, while certainly the digitalization of the global economy has brought entirely new industries and enterprises to the fore—web search, social media, artificial intelligence (AI), cloud, etc.—at least 75 percent of the value of data flows over the Internet actually accrues to traditional industries such as agriculture, manufacturing, finance, hospitality, and transportation.[3] This dynamic explains why the vast majority of the economic benefits from information and communication technologies (ICTs)—likely more than 80 percent for developed nations and 90 percent for developing ones—stem from greater adoption of ICTs within an economy, far more than the benefits generated by ICT production.[4] In other words, the value that gets created in the global economy is increasingly created digitally: In fact, some estimate that as much as half of all value that will be created across the global economy over the next decade will be done so digitally.[5] That's why one estimate predicts that 97 million new digital jobs will be created globally in the first half of this decade.[6] Similarly, a separate report finds, "If America could train just five million workers for digital jobs in the next five years, it would drive an estimated $250 billion more in U.S. GDP growth."[7] Therefore, if individual workers are going to be able to contribute value in such an economy, they'll need sufficient digital skills to be able to do so.

Digital skills can be broadly construed across two different categories. First are the digital skills needed to work directly in ICT or digital industries, including computer science skills needed to code software, AI, and other computer systems; electrical engineering skills to design semiconductors, high-performance computers, and quantum computers; cybersecurity skills; and competencies to manage data centers and telecommunications networks. It's these digital skills that have given rise to an Internet/digital tech sector that contributed $2.1 trillion of the U.S. economy in 2018, or about 10 percent of GDP.[8]

According to the U.S. Bureau of Labor Statistics' Occupational Employment and Wage Statistics survey, the number of U.S. workers in the most-relevant category—Computer and Mathematical workers—increased by 40 percent over the past two decades, from 3.3 million workers in May 2010 to 4.6 million workers by May 2020. Baselining to 2005, over the past 15 years, job growth among information technology (IT) workers has increased almost 60 percent faster than for overall jobs in the U.S. economy. (See figure 1.)

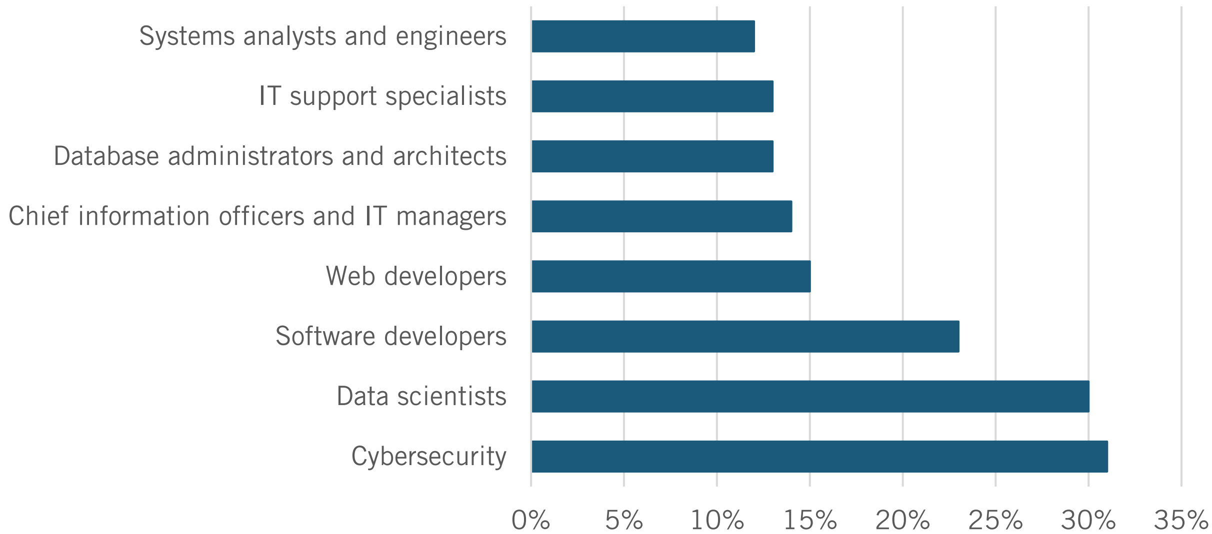
Figure 1: Indexed job growth in U.S. IT and overall workforce, 2000–2020 (2005 baseline = 1)[9]



The Computing Technology Industry Association (CompTIA) took a slightly different approach in its annual "Cyberstates" report by developing a count of technology professionals employed across the economy, including in the technology sector (e.g., software developers, network architects, database administrators); professionals employed by IT firms though not working in IT roles directly (e.g., sales, marketing, customer service professionals); and self-employed workers in the ICT-enabled "gig" economy (e.g., Uber drivers).[10] By this measure, CompTIA generated a count of 12.4 million "tech workers" in the U.S. economy, with 66 percent, or 8.2 million, of those workers directly employed in core ICT roles.

ICT jobs represent some of the fastest-growing across the economy. Burning Glass Technologies, a Boston-based labor market analytics firm, found that, from 2012 to 2017, demand for data analysts increased by 372 percent, with a subset within that job grouping (data-visualization specialists) rocketing up by 2,574 percent.[11] And that trend continues, with many ICT occupations expected to grow at four to five times the national rate over the course of this decade, led by anticipated growth in jobs in cybersecurity, data science, and software development.[12] (See figure 2.)

Figure 2: Anticipated fastest-growing ICT jobs in U.S. economy over coming decade[13]



A second category of digital skills pertains to individuals' facility with using digital tools in traditional work environments, such as the ability to work with basic Microsoft Office programs such as word processors, spreadsheets, email, or networking software; the ability to use databases or customer relationship management (CRM) tools; the ability to engage in social media or use video conferencing tools; to use mobile applications supporting point-of-service operations; to interpret the output of AI-based systems; or to use automated reality/virtual reality (AR/VR) tools to repair an automobile or jet engine. Indeed, it's this broader capacity of a nation's workforce that constitutes the transmission mechanism for digitalization to manifest its transformative impact across traditional industries from agriculture and finance to manufacturing and medicine. As the Brookings Institution's Mark Muro and his colleagues framed it in their excellent report "Digitalization and the American Workforce":

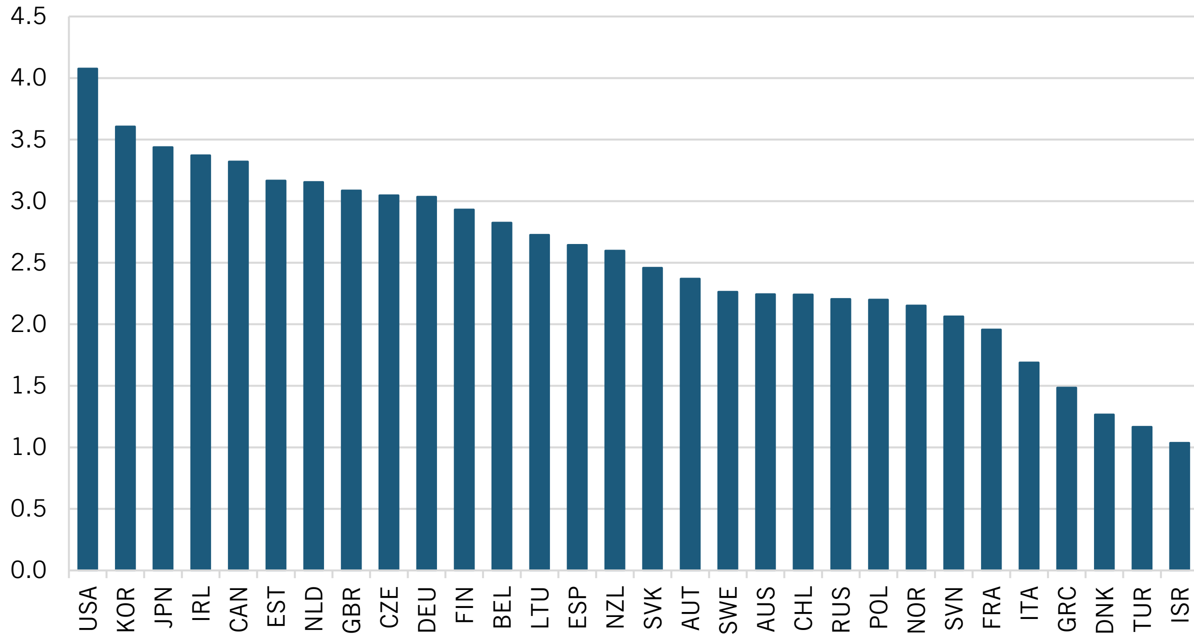
> A sizable portion of the nation's middle-skill employment now requires dexterity with basic information technology tools, standard health monitoring technology, computer numerical control equipment, basic enterprise management software, customer relationship management software like Salesforce or SAP, or spreadsheet programs like Microsoft Excel.[14]

Nations need to support the development of digital skills across both ends of this spectrum. Economists have long recognized that ICTs constitute a general purpose technology that turbocharges the productive, innovation, and business-model-generation capacity of virtually all downstream industries that utilize it.[15] Indeed, ICT represents "super capital" that has a much larger impact on productivity growth than do other forms of capital.[16] For instance, ICT capital has a three to seven times greater impact on firm productivity than does non-ICT capital. ICT workers also contribute three to five times more productivity than non-ICT workers do.[17] This dynamic explains why the digital economy has contributed to 86 percent of U.S. labor productivity growth in recent years, despite accounting for only 8.2 percent of U.S. GDP.[18]

The greater productivity of ICT-industry workers, or workers who possess greater levels of digital skills, explains why such workers are often able to command higher wages. For instance, the

Organization for Economic Cooperation and Development (OECD) has found that a 10 percent increase in the ICT-task intensity of jobs (at the country mean) correlates to an average 2.5 percent increase in hourly wages across OECD economies, with the United States experiencing the highest effect at 4.08 percent. (See figure 3.)

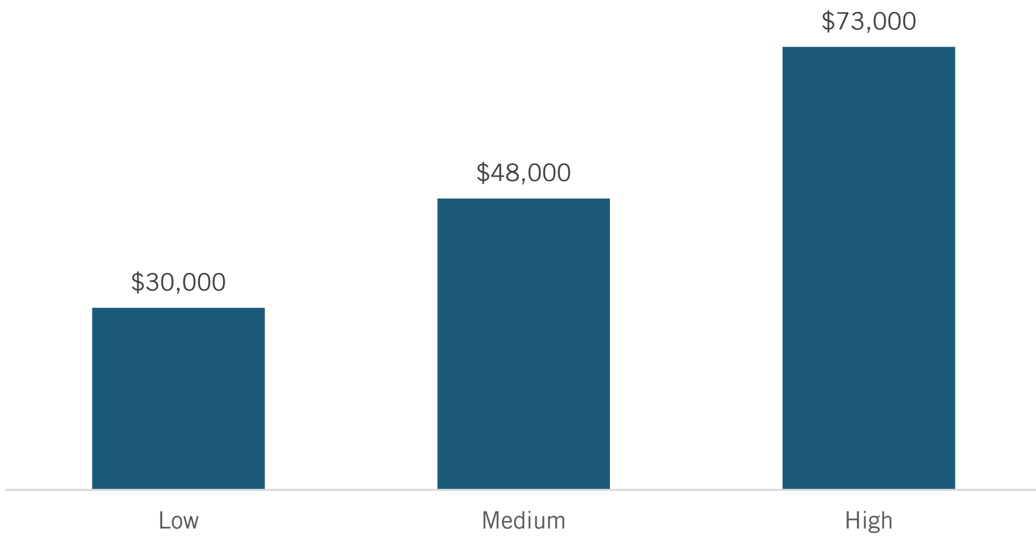
Figure 3: Returns on ICT tasks—percentage change in hourly wages for a 10 percent increase in ICT task intensity of jobs (at the country mean), 2012 or 2015[19]



The finding that jobs involving high digital-task intensity and greater levels of digital skills earn more has been corroborated repeatedly. Brookings' 2017 "Digitalization and the American Workforce" report examines the digital content of 545 occupations covering 90 percent of the U.S. workforce in all industries from 2001 to 2016. The report leverages the Occupation Information Network (O*Net) database, which surveys workers on their knowledge, skills, tools and technology, education and training, and work activities required to perform their jobs.[20] Here, two of O*Net's three technology-related variables are relevant: "Knowledge: Computer and electronics" (which measures the overall knowledge of computers and electronics required by a job) and "Work activity–interacting with computers" (which quantifies the centrality of computers to the overall work activity of the occupation).[21] Brookings used this to develop occupational digitalization scores for 545 occupations across 23 highest-level industries, segmenting occupations into 3 tiers of digitalization: low, medium, and high.

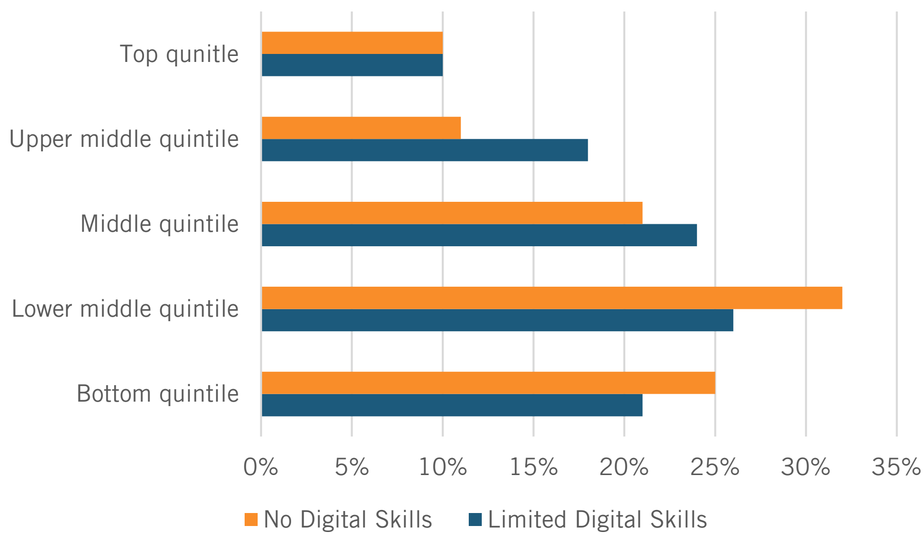
Not surprisingly, Brookings found that the mean annual wage for workers in highly digital occupations reached $72,896 in 2016, with workers in middle-level digital jobs earning $48,274, and those in the least digitally intense positions earning $30,933. (See figure 4.) Importantly, Brookings found that digitalization scores have significant and positive effects on real annual wages even when controlling for education level, and that the wage premium for computer skills nearly doubled between 2002 and 2016. To wit, in 2002, a one-point increase in digitalization score predicted a $166.20 (in 2016 dollars) increase in real annual average wages for occupations with the same education requirements; by 2016, this wage premium had almost doubled to $292.80.[22]

Figure 4: Mean annual wage by digitalization level, 2016[23]



Brookings findings have also been corroborated by those from the most-recent OECD Survey of Adult Skills (formally known as the "Programme for the International Assessment of Adult Competencies" or PIAAC, and subsequently elaborated upon), which assesses workers from over 40 nations on 11 ICT-related measures ranging from simple use of the Internet to use of a word processor, spreadsheet software, or programming language.[24] As reported by the National Skills Council in its report "The New Landscape of Digital Literacy," half of workers with limited or no digital skills have lower earnings. To wit, among workers reporting possessing no digital skills, 32 percent were in the lower-middle quintile of wage earners and 25 percent were in the bottom quintile, while among those reporting possessing limited digital skills, 26 percent were in the lower-middle quintile and 21 percent in the bottom quintile.[25] (See figure 5.)

Figure 5: Earnings of U.S. workers ages 16–64 in quintiles by digital skill levels[26]



ASSESSING THE STATE OF DIGITAL SKILLS IN THE U.S. WORKFORCE

This section assesses the state of digital skills across the U.S. workforce broadly, first by industry and occupation, then across various IT platforms, and finally in terms of international comparisons.

Assessing U.S. Workforce Digital Skills Broadly, By Industry, and By Occupation

The OECD's PIAAC survey categorizes adult workers into four levels of digital skills: no digital skills, limited digital skills, proficient digital skills, and advanced digital skills.[27] (Technically, the survey tests for "digital problem solving in technology-rich environments.")[28] Individuals with no digital skills failed to meet one or more of three basic digital skills criteria: 1) prior computer use; 2) willingness to take the computer-based assessment; and 3) ability to complete four out of six extremely basic computing tasks, such as using a mouse or highlighting text on screen.[29] Individuals with limited digital skills could complete only very simple digital tasks involving a generic interface and a few steps (e.g., placing incoming Outlook emails into specified folders).[30] Those possessing proficient digital skills were capable of using basic digital productivity tools (e.g., Microsoft Outlook), and could use digital tools such as the sort function in spreadsheets to solve problems, yet still struggled with tasks involving the use of both generic and specific technology applications.[31] Lastly, those possessing the most-advanced digital skills in the PIAAC survey have facility in "the use of both generic and more specific technology applications… [can navigate] across pages and applications… [and can solve tasks that] may involve multiple steps and operators."[32]

While it should be apparent that even the above-referenced digital-problem solving skills measures don't constitute "tests" for extremely high levels of digital aptitude, the PIIAC data reveals that even then fully one-third of American workers lack digital skills, with 13 percent of U.S. workers having no digital skills and 18 percent having at best limited digital skills, while 35 percent could be deemed proficient and 33 percent advanced in digital skills. (See figure 6.) In essence, one in six working-age Americans are unable to use email, web search, or other basic online tools.[33] As the National Skills Council observed, there is significant digital skills knowledge fragmentation among U.S. workers: Many may be comfortable using smartphone apps but unfamiliar with how to operate a mouse, use Microsoft Office productivity tools, or even upload employment applications to websites.[34] In part, that's because 23 percent of U.S. households do not own a desktop or laptop computer, while over 7 percent of all Americans simply don't use the Internet.[35] This digital divide hits U.S. minority groups particularly hard, with 23 percent of African Americans and 25 percent of Latino respondents to a 2019 Pew Research Center study reporting having smartphone-only Internet access.[36]

Figure 6: Extent of digital skills in the U.S. workforce according to OECD PIAAC survey data[37]

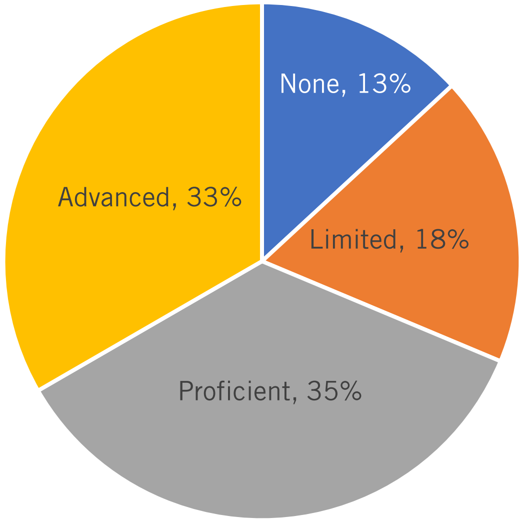


Table 1: Percentage of workers with no or limited digital skills, selected industries[38]

Industry	Percentage of Workers With No Digital Skills	Percentage of Workers With Limited Digital Skills	Combined Percentage of Workers With Limited or No Digital Skills
Construction, transportation, and storage	22%	28%	50%
Retail, wholesale, and auto repair	14%	23%	37%
Hospitality and other services	18%	18%	36%
Manufacturing	16%	19%	35%
Administrative and support services; arts, entertainment, and recreation	13%	22%	35%
Health and social work	12%	21%	33%
Finance, insurance, and real estate	6%	14%	20%
Education	5%	11%	16%

The lack of workforce digital skills is particularly acute in certain industries. Across the U.S. construction, transportation, and storage industry, fully half of all workers have no or only limited digital skills, while that share is over one-third across the health and social work, manufacturing, hospitality, and retail and wholesale industries. (See table 1.) The lack of digital skills in the manufacturing sector is particularly concerning, especially because jobs in U.S. manufacturing increasingly demand a facility with digital skills, which is important for individual workers to be both competitive and productive, and for broader U.S. manufacturing industries as well.

Unfortunately, despite this rather significant gap in digital skills across the U.S. workforce, the digital skills requirements of U.S. occupations continues to increase apace. Brookings' study "Digitalization and the American Workforce" finds that, from 2002 to 2016, the share of employment in occupations with high digital content (defined as occupations with digital scores above 60 on a 100-point scale) more than tripled, from 4.8 to 23 percent of employment, while employment in occupations with medium digital content requirements increased from 39.5 to 47.5 percent, and the share of jobs with low digital content requirements nearly halved, shrinking from 55.7 to 29.5 percent. (See figure 7.) In essence, over 70 percent of U.S. jobs now require middle- to high-level digital skills. In absolute terms, Brookings found that, as of November 2017, over 32 million U.S. workers were employed in highly digital jobs, 66 million held moderately digitally intense positions, and only 41 million were in jobs requiring only low levels of digital skills.[39] Archetypal occupations requiring high levels of digital skills included ICT workers, electrical engineers, and financial managers; occupations requiring medium digital skills levels included attorneys, mechanics, and registered nurses; while examples of low-digital-skill-level occupations included security guards, restaurant cooks, and personal care aides.

Brookings further found that digitalization scores rose in the overwhelming number of analyzed occupations (517 of the 545) from 2002 to 2016. Moreover, Brookings found that "job creation in the last few years has heavily favored digitally oriented occupations," with nearly 4 million of the 13 million new jobs created from 2010 to 2016, nearly 30 percent, requiring high-level digital skills.[40] (See figure 8.)

Figure 7: U.S. employment by levels of digitalization[41]

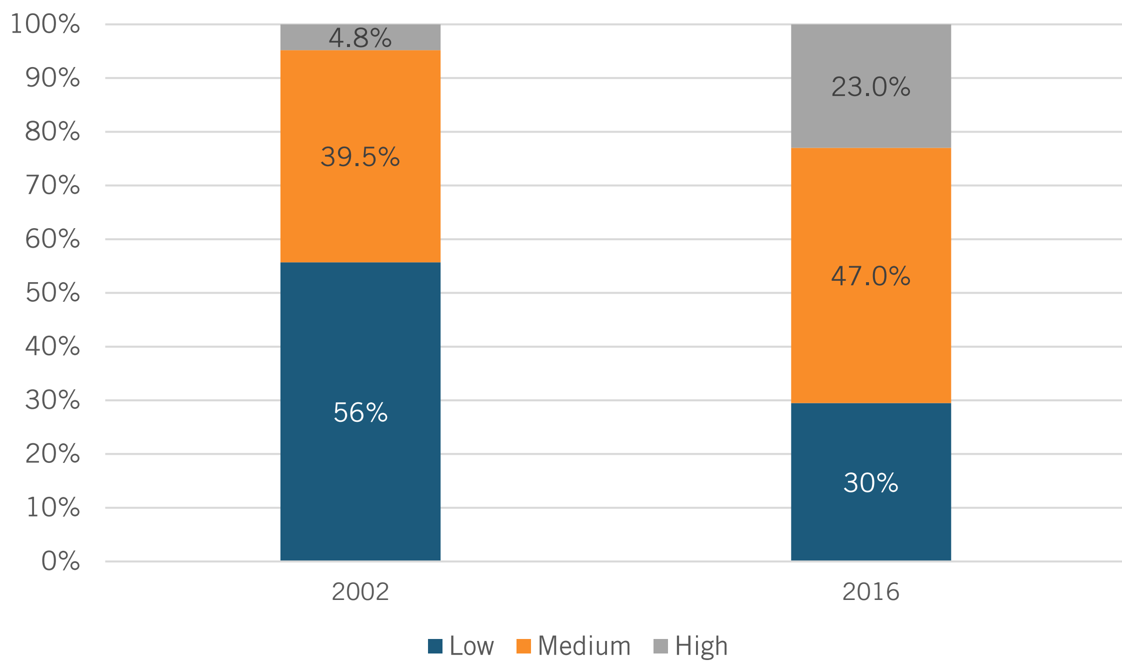
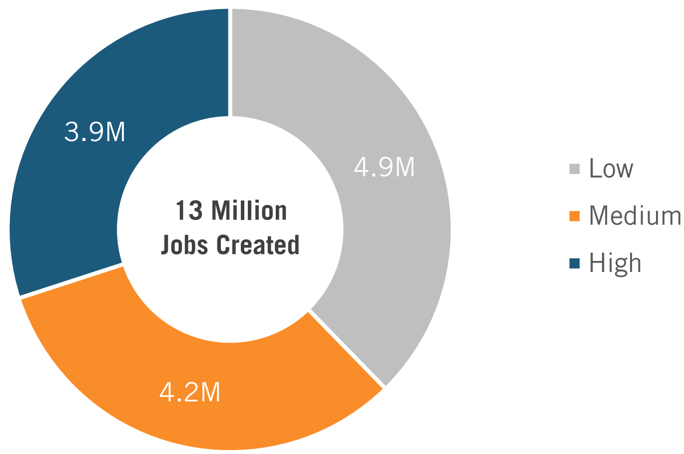


Figure 8: U.S. jobs created by digital skill level, 2010–2016[42]



The extent of industry digitalization varies widely, with jobs in the ICT industry—where 70 percent require high levels of digital skills and 29 percent medium levels—unsurprisingly leading, followed by jobs in the finance and insurance industry and the utilities sector (See figure 9). Perhaps most notable are the digital skills requirements of occupations in advanced manufacturing. Whereas, in 2002, 47 percent of jobs required only limited digital skills (and just 15 percent required advanced skills and 38 percent middle-level digital skills), by 2016 the share of advanced manufacturing jobs requiring high levels of digital skills increased to 34 percent, those in the mid-tier increased to 48 percent, and those needing only the least digital skills shrank by nearly 30 percentage points, to a mere 18 percent share.

Figure 9: Share of sector employment by digital score, 2016[43]

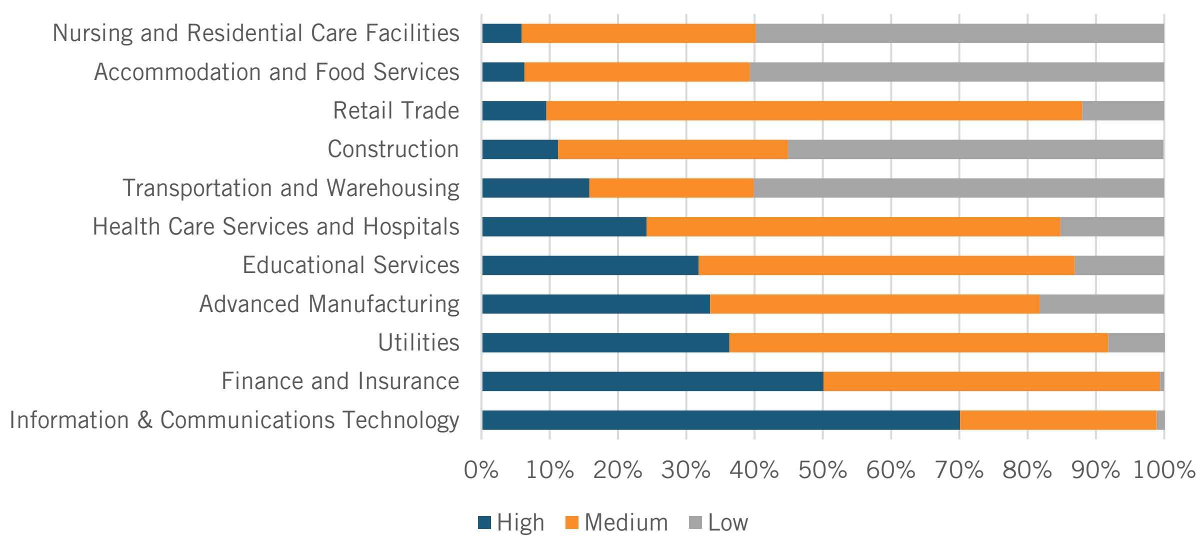
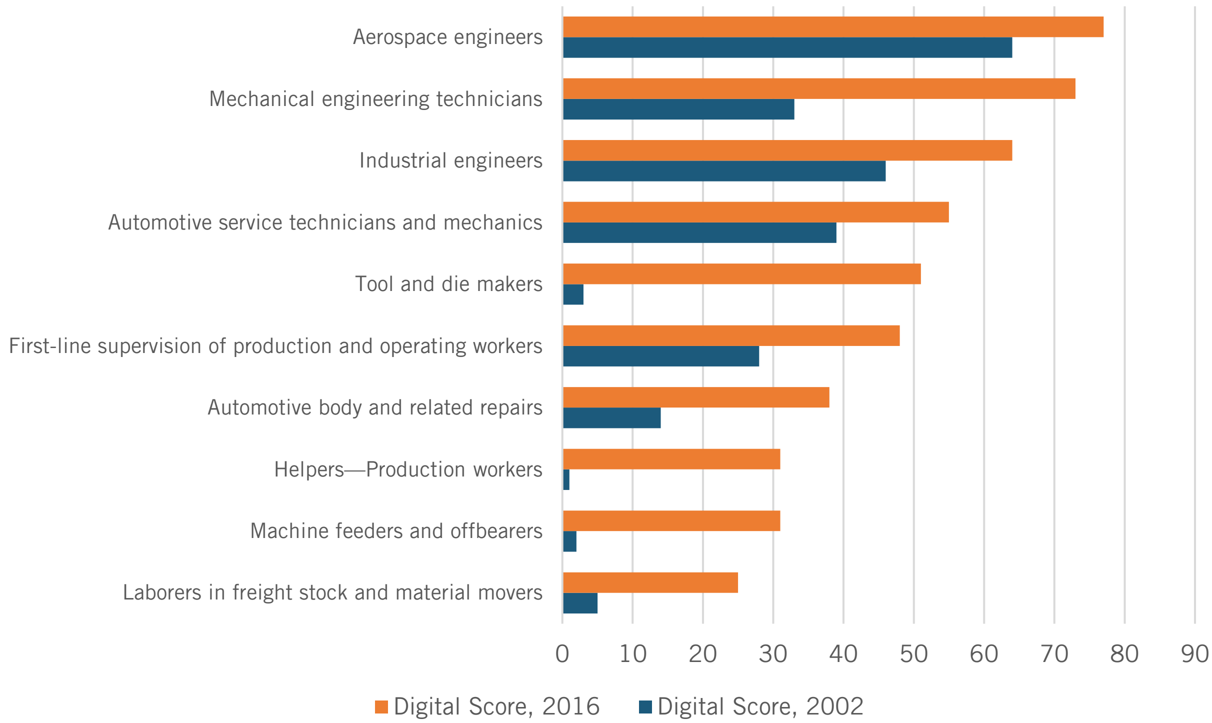


Figure 10: Digital skill ratings for occupations in advanced manufacturing[44]



Notably, technology-oriented occupations are increasing their share of advanced manufacturing employment at the expense of routine occupations. For instance, from 2006 to 2016, the U.S. manufacturing industry added 73,130 workers in software development for systems software and 51,900 as mobile application software developers (a job category that scarcely existed in 2002) as well as another 15,000 jobs in computer systems analysis, graphic design, and operations research analysis. Conversely, the industry shed nearly 20,000 jobs in routine roles such as machine feeding.[45] The advent of digital manufacturing has introduced not just new skill requirements and responsibilities but even entirely new types of jobs. For instance, a recent report by MxD and Manpower Group, "The Digital Workforce Succession in Manufacturing," identifies 165 completely new job roles pertinent to digital manufacturing and design.[46]

Moreover, across virtually every occupation in advanced manufacturing, the need for digital skills increased from 2002 to 2016. For instance, whereas for tool and die making the digital component of the job was virtually nil in 2002, by 2016, this had changed to become a job with a medium level of digital skills content relative to other jobs in the U.S. workforce. And for advanced manufacturing jobs that required a medium level of digital skills in 2002—such as for automotive service technicians and mechanics, industrial engineers, and mechanical engineering technicians—by 2016, this had jumped to requiring a high level of digital skills. (See figure 10.)

It should also be noted that, in general, the higher the mean digital score for occupations in an industry, the greater that industry's output, productivity, and wage changes were from 2010 to 2016. As the Brookings report notes, "In an era of slowing productivity growth, the most highly digitalized sectors led the U.S. economy in productivity increases" with the ICT and media sectors increasing their annual productivity by more than 2.5 percent.[47] (See table 2). By contrast, productivity in medium-skilled digital sectors such as health care and advanced manufacturing grew by only a modest 0.7 and 0.3 percent per year, while the lagging hospitality, construction, nursing and residential care, and accommodation and food services industries experienced negative productivity growth.[48] In general, the more highly digitalized industries in the Brookings study also realized higher output and wage growth from 2010 to 2016. In sum, the Brookings report showcases the ever-increasing importance of digital skills across virtually every occupation and industry in the U.S. economy.

Table 2: Industry mean digitalization scores and economic performance, 2010–2016[49]

		Compound Annual Growth Rate, 2010–2016		
Industry	**Mean Digital Score, 2016**	**Output Change**	**Productivity Change**	**Wage Change**
Professional, scientific, and technical services	55	3.3%	0.3%	1.4%
Finance and insurance	55	1.4%	0.1%	1.8%
Media	52	2.7%	2.6%	3.0%
Management of companies and enterprises	51	4.7%	1.9%	2.2%
Healthcare services and hospitals	46	2.8%	0.7%	1.0%
Information and communications technology	44	4.6%	3.9%	4.8%
Utilities	44	0.2%	0.2%	2.0%
Wholesale trade	44	2.6%	1.4%	1.3%
Oil and gas extraction	43	9.3%	6.6%	0.3%
Educational services	41	0.2%	-2.3%	0.0%
Retail trade	41	2.6%	1.1%	0.9%
Advanced manufacturing	39	1.5%	0.3%	0.9%
Transportation and warehousing	33	1.4%	-1.6%	0.9%
Basic goods manufacturing	33	-0.1%	-1.2%	0.8%
Construction	33	2.7%	-0.6%	1.4%
Nursing and residential care facilities	32	1.2%	-0.7%	0.9%
Accommodation and food services	30	2.4%	-0.7%	1.7%
Mining (except oil and gas)	30	-4.6%	-3.0%	0.0%

Assessing U.S. Workforce Digital Skills Across Specific Digital Technologies

Beyond examining U.S. workforce digital skills broadly across an economy, it's also possible to consider them through the lens of facility with emerging digital technologies, such as AI and AR/VR.

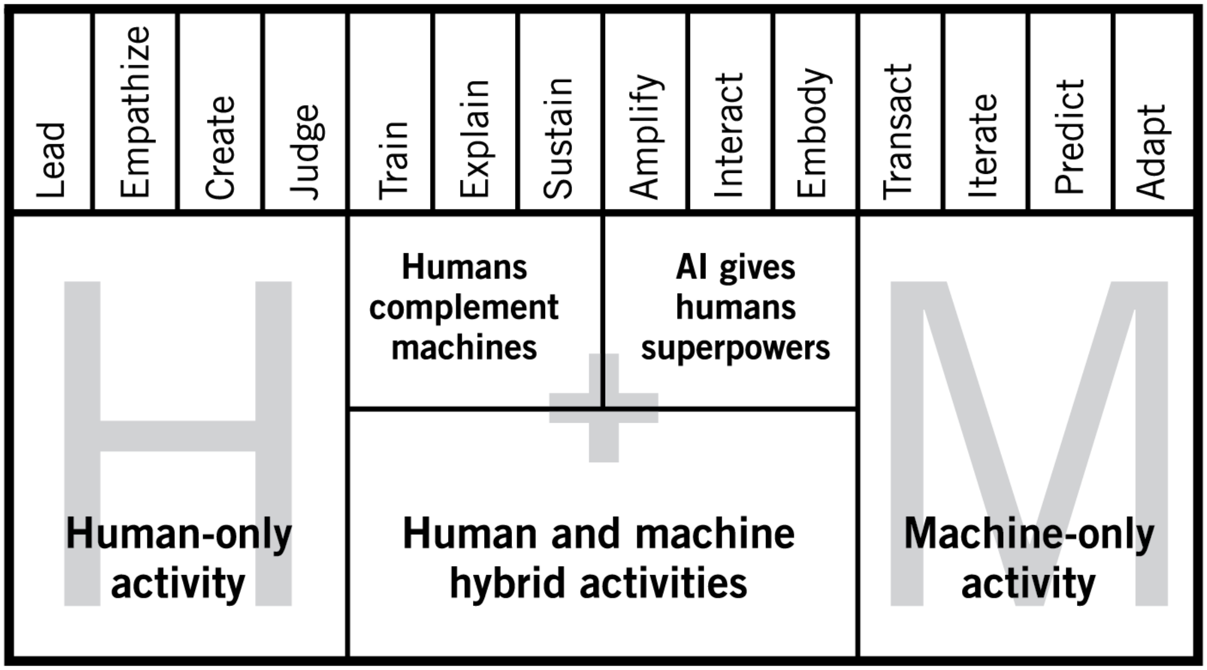
U.S. Workforce Digital Skills in AI

AI represents an increasingly important driver of global economic growth. For instance, a 2018 McKinsey Global Institute report estimates that, by 2030, applications of AI will boost global productivity by 1.2 percent annually, increasing the size of the global economy by $13 trillion.[50] Elsewhere, an Accenture report estimates AI would contribute to a U.S. economy $8.3 trillion larger by 2035.[51] Accenture further estimated that companies "investing in AI and in human-machine collaboration" will boost their revenues by 38 percent between 2018 and 2022.[52]

As Paul Daugherty and James Wilson wrote in their excellent book *Human + Machine: Reimaging Work in the Age of AI*, the AI era has given rise to numerous new-to-the world jobs, including data scientist/data analyst, AI applications developer, AI applications engineer, cognitive systems engineer, machine-learning engineer or specialist, collaborative robotics specialist, digital twin analyst or architect, data-quality analyst, interaction modeler, algorithmic forensics analyst, human-computer interaction specialist, and explainability strategist.[53] Beyond creating entirely new jobs, a 2019 Brookings report, "What Jobs Are Affected By AI" finds that "virtually every occupational group" in the U.S. economy would be impacted by AI.[54] The report also finds that 740 out of 769 occupations assessed "contain a capability pair match with AI patent language, meaning at least one or more of its tasks could potentially be exposed to, complemented by, or completed by AI."[55]

An essential feature of the AI era will be the need for humans and machines to work together. As developed in their book *Human + Machine: Reimaging Work in the Age of AI,* Daugherty and Wilson identified a set of roles wherein human capacity will remain supreme (tasks such as leading, empathizing, creating, and judging) and a set of tasks wherein machines are likely to outperform humans (e.g., transacting, iterating, predicting, and adapting). (See figure 11.) Yet in the middle lies a set of tasks wherein humans will enable machines (in functions such as training, explaining, and sustaining) and ones wherein "AI will give humans superpowers," thus augmenting human capabilities (in functions such as amplifying, interacting, and embodying).[56] It's in this "missing middle," as Daugherty and Wilson contended, where humans and machines complement and extend the potential of one another—and give businesses significant potential to reimagine their existing work processes "to take advantage of collaborative teams of humans working alongside machines."[57] They argued, "The simple truth is that companies can achieve the largest boosts in performance when humans and machines work together as allies, not adversaries, in order to take advantage of each other's complementary strengths."[58]

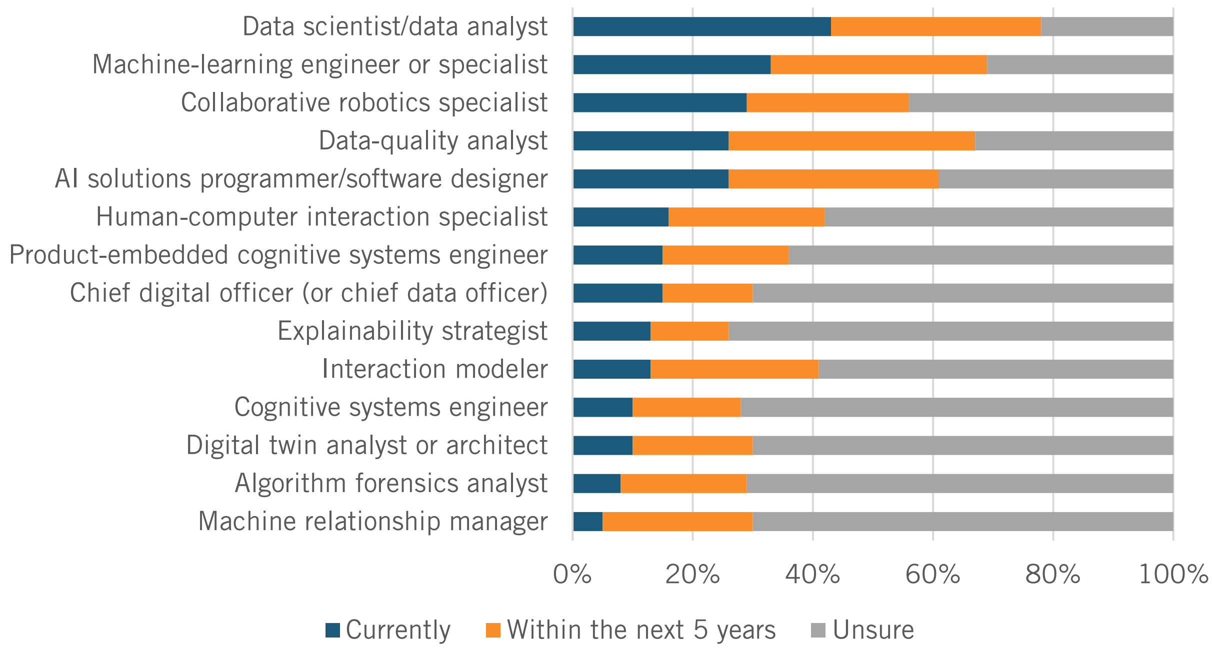
Figure 11: Roles of humans and machines in the AI era[59]



Thus, as the Information Technology and Innovation Foundation (ITIF) wrote in "The Manufacturing Evolution: How AI Will Transform Manufacturing and the Workforce of the Future," one of the ironies of the AI era is that as AI becomes more prevalent, investing in people becomes all the more important.[60] Yet there is a disconnect here. For instance, even though almost half of 1,200 CEOs and senior executives surveyed by Accenture in a recent study identified digital skills shortages as a key workforce challenge, only 3 percent reported that their organizations had plans to significantly increase investment in training programs over the next three years.[61] Perhaps one of the challenges here is that employees are actually more ready for the AI transformation than their employers think they are. For instance, only one-quarter of executives in the Accenture study reported they "believe our workforce is ready for AI adoption."[62] However, 68 percent of highly skilled workers and nearly half of the lower-skilled workers were enthusiastic about AI's potential impact on their work, while 67 percent of workers considered it important to develop their own skills to work with intelligent machines. Moreover, another survey of workers finds that while nearly all (92 percent) believe the next generation of workplace skills will be radically different from the prior one, 87 percent believe that, within the next five years, new technologies such as AI will improve their work experience.[63]

In 2019, ITIF and the Manufacturers Alliance surveyed over 200 mid-sized U.S. manufacturers with sales of generally between $500 million and $10 billion, inquiring how they anticipated AI would transform their manufacturing operations and workforces.[64] The survey finds that it remains early days for the introduction of AI jobs in U.S. manufacturing, with 72 percent of companies surveyed having yet to introduce such new types of AI jobs. However, manufacturers expect that situation to change rapidly over the next five years. Among the manufacturers surveyed, by 2024, nearly 80 percent expect to employ data scientists/data analysts (up from 43 percent today), 70 percent expect to employ machine-learning engineers or specialists (up from 33 percent today), 56 percent expect to employ collaborative robotics specialists (up from 29 percent today), and 60 percent expect to employ AI solutions programmers or software designers (up from 26 percent today). (See figure 12.) Surveys such as these make it clear: Facility with AI skills will soon become a critical component of not just manufacturing jobs, but many other jobs across the entire U.S. economy.

Figure 12: AI-related jobs U.S. manufacturers anticipate introducing[65]



U.S. Workforce Digital Skills in AR/VR

AR/VR—immersive technologies that enable users to experience digitally rendered content in both physical and virtual spaces—offers promising opportunities to enhance workforce training. These technologies can give workers hands-on experience in low-risk simulated environments as well as real-time, on-the-ground guidance, which in turn can reduce operational costs, increase engagement, and provide valuable insight for future training.[66] Because of this, there is growing interest in AR/VR training solutions across many industries. According to the research firm IDC, nearly one-third of Global 2000 (G2000) manufacturers plan to be using immersive tools by 2022.[67] Thanks to that kind of penetration, a 2019 report by PwC predicts that VR and AR could add $1.5 trillion to the global economy by 2030, with development and training contributing $294.2 billion.[68] And in a 2018 survey of automotive, manufacturing, and utilities industry executives, a significant majority of respondents indicated they believed AR/VR technologies would become mainstream in their organizations within the next five years.[69] Given the demonstrated benefits and enthusiasm around these tools, it is hardly surprising that the market for immersive training solutions is expected to grow from $20.6 billion in 2020 to $463.7 billion in 2026.[70]

Advanced, highly specialized, and high-risk industries are natural candidates for AR/VR training tools, as immersive solutions allow workers to repeatedly practice certain tasks without having to worry about making costly or dangerous mistakes. For example, VR welding simulators allow students to practice in a safe environment and receive real-time feedback on their performance.

One 2012 study estimates that integrating these tools in trainings could lead to over $200 in savings per student.[71] Immersive solutions can also provide ongoing training and knowledge transfer on the ground. For example, industrial manufacturer Howden developed an AR training system to streamline expert knowledge sharing across global product units and sales teams.[72]

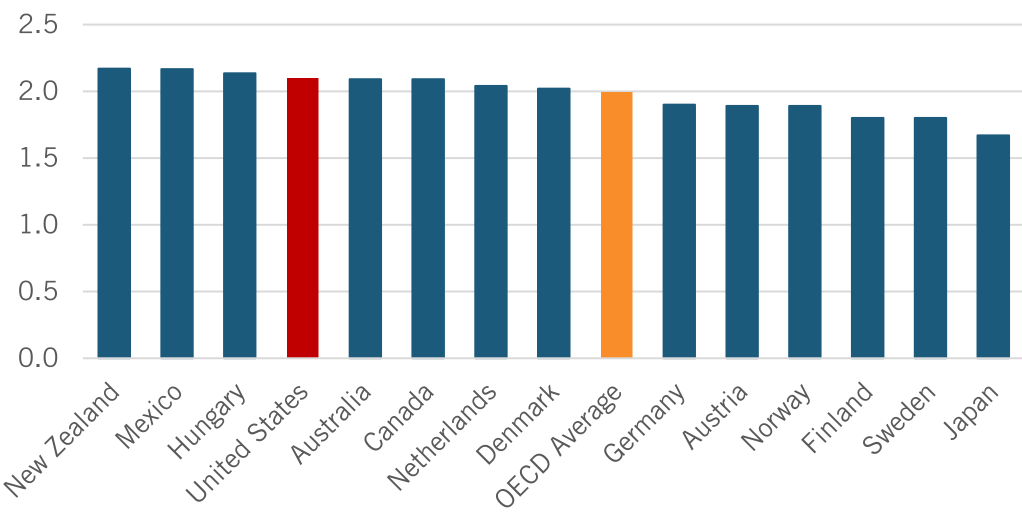
AR/VR solutions can improve workforce training beyond manufacturing and other advanced industries. For example, Walmart uses a VR experience to allow floor associates to practice different scenarios, including "holiday rush" modules that "simulate the high-stakes, chaotic environment of Black Friday."[73] During the pilot phase, the training resulted in notably higher employee satisfaction, knowledge retention, and test scores.[74] Similarly, JetBlue partnered with the AR/VR solution developer Strivr Labs to develop VR training for technicians working on JetBlue aircraft.[75] Even Kentucky Fried Chicken now trains workers on food safety using VR goggles.[76]

Immersive training is also increasingly popular in health care education. For example, the HoloAnatomy platform developed by Case Western Reserve University uses Microsoft HoloLens mixed reality (MR) headsets to provide medical students with scientifically accurate anatomical models they can interact with in real time.[77] HoloLens has proven to be an engaging, effective, and cost-efficient alternative to traditional cadaver-based anatomy education.[78]

Assessing U.S. Workforce Digital Skills in International Comparisons

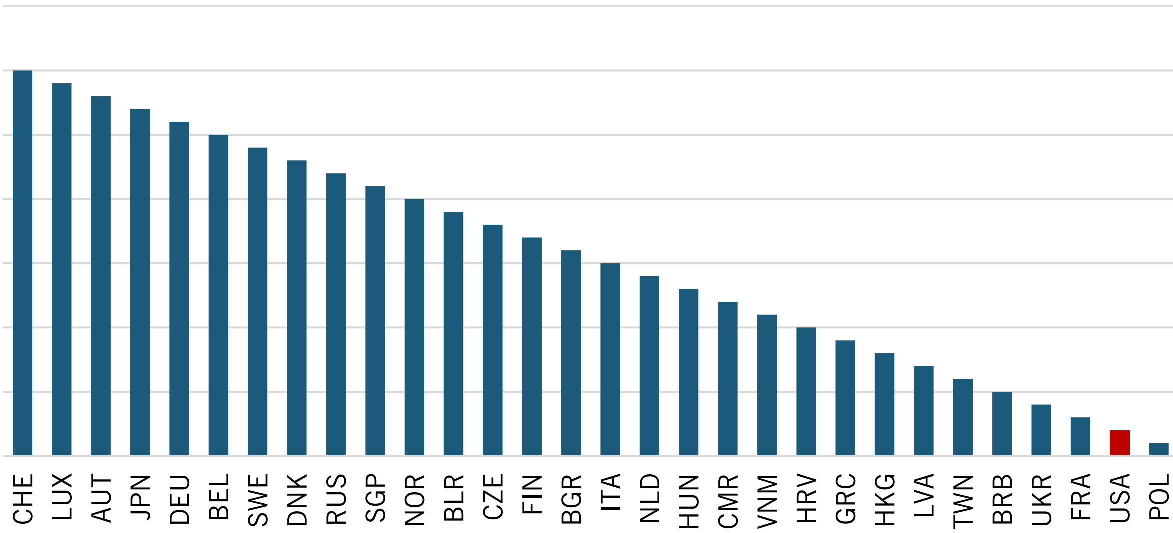
The United States performs mixed, and increasingly underwhelmingly, in international comparisons of digital skills. The PIIAC survey measured "use of ICT skills at work" across 14 OECD countries in 2012. On this index, the United States ranks fourth with a score of 2.1, which is ahead of the OECD average of 1.99, yet behind leaders New Zealand (and surprisingly, Mexico) with a score of 2.17. (See figure 13.)

Figure 13: Use of ICT skills at work in OECD PIIAC survey, 2012[79]



A much more recent study, the "2021 Global Skills Report" conducted in 2021 by online education provider Coursera, finds that "despite the rapid rate of digital transformation, U.S. digital skills proficiency falls behind that of many countries in Europe and Asia."[80] The study, which measures learners on the Coursera platform from 100 countries across the business, technology, and data science domains, ranks the United States 29th globally, trailing behind the two world leaders from Europe (Switzerland and Luxembourg) and third-ranked Japan.[81] (See figure 14.) Relative to learners from the 100 other countries in the study, Coursera found U.S. learners lagged behind across a number of digital economy skills, including operating systems, cloud computing, and mathematics, but "show room for growth" in business skills such as communication, entrepreneurship, and leadership and management.[82]

Figure 14: Top-30 Countries in Coursera's 2021 Global Digital Skills Rankings[83]



BEST PRACTICES IN TEACHING DIGITAL SKILLS TO THE U.S. WORKFORCE

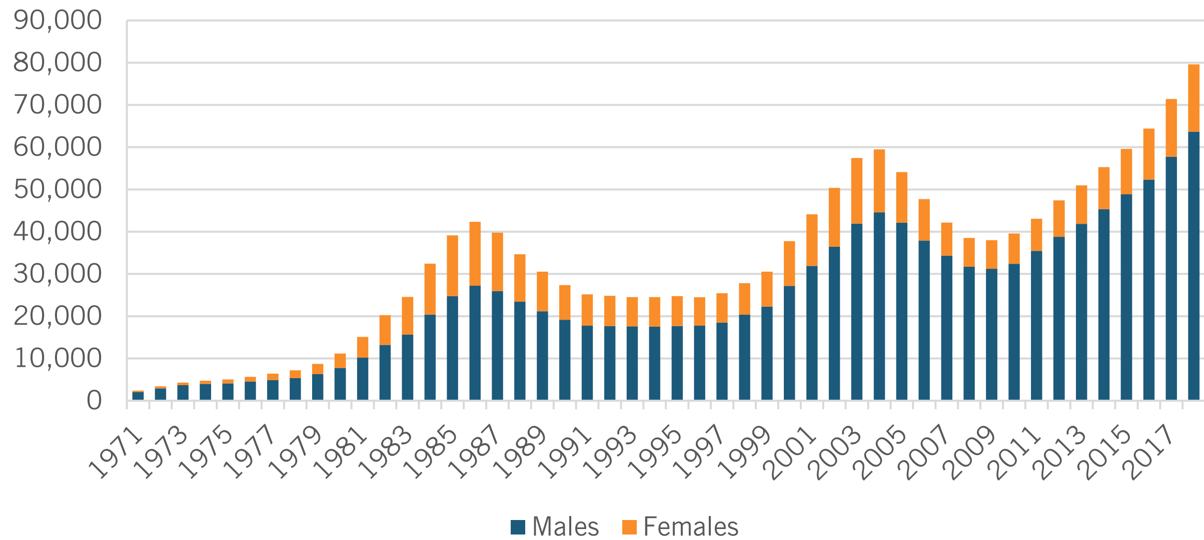
When thinking about education at the societal level, policymakers need to consider both education for those entering the workforce from the traditional education system (e.g., high schools, universities, and community colleges) and reskilling those currently in the workforce with the skills—digital and otherwise—needed to remain competitive. This section examines the state of digital skills and computer science training in U.S. schools and highlights some of the best programs and practices across America seeking to teach digital skills in both K-12 education and to the broader workforce.

U.S. Computer Science Education

Not only does computer science represent a powerful educational tool for fostering critical thinking, problem-solving, and creativity, but computer skills and competencies are also in high demand among employers across a wide range of industries, not just the technology industry.[84] For this reason, ITIF has long called for computer science to be seen as a core science on par with more traditional high school offerings such as biology, chemistry, and physics. Unfortunately, in the United States today, only about one-quarter of high schools teach computer science.[85] And more high school students in California take a class in pottery than in computer science.[86] At the collegiate level, for years, the United States has been failing to produce adequate numbers of computer science graduates. One study estimates that, from 2014 to 2024, the U.S. annual computer/IT college graduates totaling about 60,000 would be 40,000 graduates short of annual U.S. labor market needs.[87] In other words, it foresees a gap of 400,000 needed computer science/IT graduates over that decadal period.

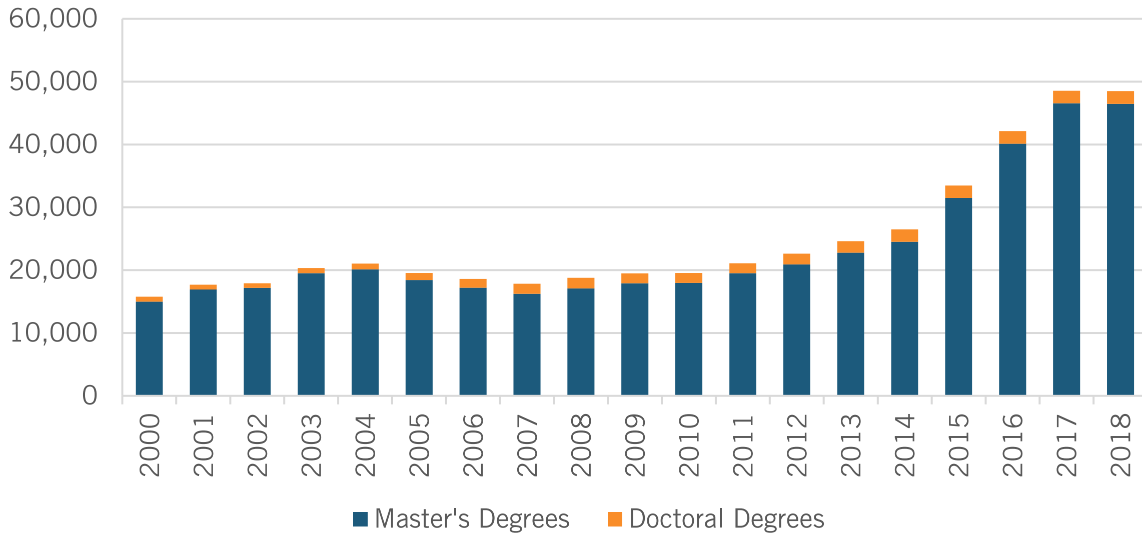
U.S. collegiate computer science education has grown in fits and starts. Prior to recent years, the number of bachelor's U.S. computer science students peaked in 2004, with 44,585 graduates, before beginning a steady decline throughout the 2000s and bottoming out with 31,213 graduates in 2009, a figure that was down over 30 percent from the 2004 level. But since then, the number of bachelor's computer science degrees have steadily increased, more than doubling from 2009 to tally 79,598 bachelor's degrees (63,704 for men and 15,894 for women) in 2018. (See figure 15.) In fact, the number of computer science bachelor's degrees awarded has increased by one-third from 2013 to 2018.

Figure 15: U.S. bachelor's degrees in computer science, 1971–2018[88]



The number of advanced computer science degrees awarded by U.S. universities also markedly increased over that time period. In fact, it more than doubled from 2013 to 2018, increasing from 22,782 to 46,468. (See figure 16.) However, the number of computer science doctoral degrees awarded increased only modestly from 1,834 to 2,017. While the growth in U.S. computer science degrees is laudable, one concern is that U.S. universities are increasingly training foreign-born students in these fields. Indeed, 79 percent of graduate students in U.S. university computer science programs (and 81 percent in electrical engineering) are foreign born.[89] Of those international students, a 2019 Congressional Research Service report finds that nearly 70 percent of foreign students enrolled in STEM (science, technology, engineering, and mathematics) courses came from China and India.[90]

Figure 16: U.S. advanced degrees in computer science, 2000–2018[91]



Other Notable Digital Skills Education Efforts

Women constitute an underrepresented asset in America's technology workforce. Nationally, women represent approximately 49 percent of the U.S. workforce, but only 26 percent of "tech occupations" (as defined by CompTIA, as previously explained).[92] Brookings found similar results, noting that "women remain significantly underrepresented in such highly digital positions as computer and mathematical occupations (25.5 percent) and engineering (14.2 percent)."[93] In fact, in 1995, 37 percent U.S. of computer scientists were women, and that figure has fallen to just 24 today.[94] This concords with the ITIF research finding that while U.S. women today receive the majority of bachelor's, master's, and Ph.D. degrees from U.S. universities (59, 62, and 51 percent, respectively), they are seriously underrepresented in STEM fields, earning just 21.7 percent of Ph.D.'s awarded in computer science for industry.[95] (See figure 17.) In 2018, women accounted for an even smaller share of bachelor's degrees awarded in computer science, just 19.9 percent. (See figure 18.) Low enrollment numbers for women in STEM fields such as computer sciences is one reason why ITIF found in a 2016 report that women represent only 12 percent of U.S. innovators.[96]

Figure 17: Percentage of Ph.D. degrees earned by women by field, 2002–2018[97]

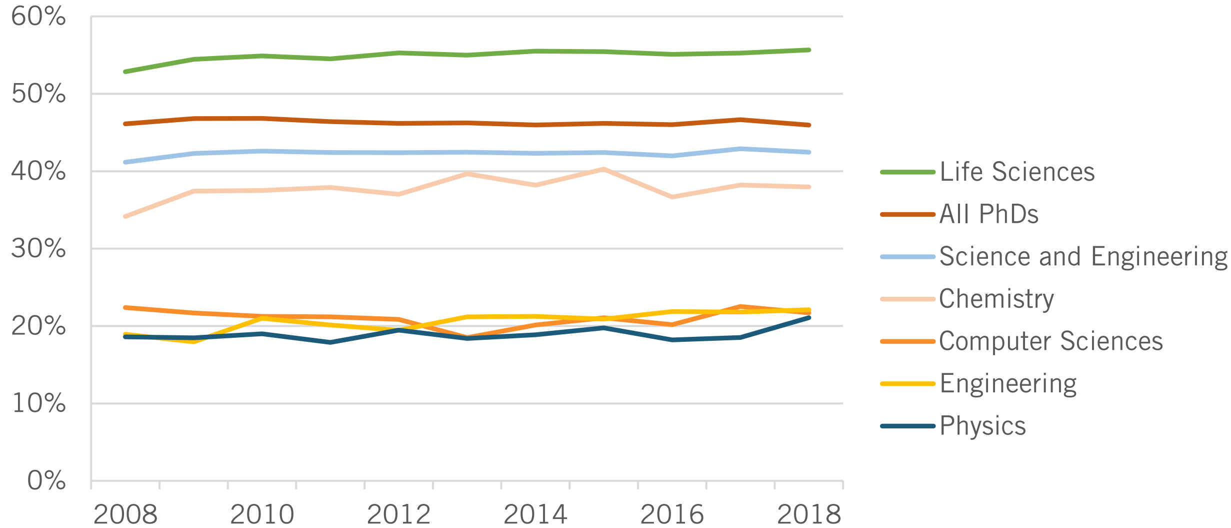
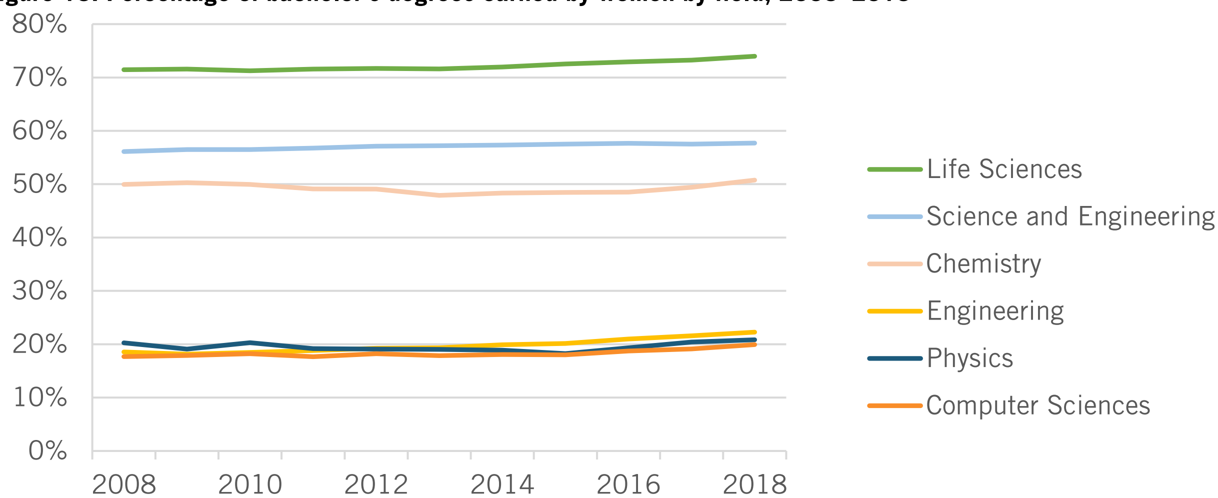


Figure 18: Percentage of bachelor's degrees earned by women by field, 2008–2018[98]



A number of initiatives have been launched to attract more women, especially young girls, into the digital technology world. For instance, the mission of TechGirlz is to inspire middle school girls to explore the possibilities of technology to empower their future careers.[99] TechGirlz has shared its curriculum with companies, organizations, and schools in over 20 countries, and more than 25,000 girls have attended its hands-on TechShopz, resulting in 82 percent of participating girls changing their mind positively about pursuing a career in tech.[100] Elsewhere, Girls Who Code is a nonprofit organization whose mission is to close the gender gap in technology and computer science, seeking to inspire more girls to become computer scientists and engineers. Girls Who Code has taught over 450,000 young women through its in-person programming—including its Summer Immersion Program, Clubs, and College Loops—and reached hundreds of thousands more through its online resources, campaigns, books, and advocacy work.[101] A separate program, Black Girls Code, builds pathways for young females of color to embrace tech jobs by introducing them to skills in computer programming and technology.[102]

Another notable, broader effort to teach young students digital skills is the Microsoft Imagine Academy, which gives students and educators the curricula and certifications they need to succeed in a technology-driven economy.[103] Imagine Academy has programs around computer science, IT infrastructure, and data science designed variously for young students and mid-career professionals alike. A number of U.S. states, including Arkansas, Iowa, and North Carolina, have partnered with the Imagine Academy to develop curricula accelerating development of career and technology education skills.[104] Separately, Microsoft has created the Microsoft Professional Program, which offers certifications in data science, AI, AI applications development, and data-analyst roles. These certifications help individuals gain technical, job-ready skills and accrue real-world experience through online courses, hands-on labs, and expert instruction.[105] Similarly, Microsoft has also created the AI Business School, an online masters-level curriculum that educates executives on how to lead their organizations on an "AI transformation journey."[106]

As noted, the advent of digital manufacturing has introduced not just new skill requirements and responsibilities but even entirely new types of jobs in the manufacturing domain. The aforementioned "The Digital Workforce Succession in Manufacturing" report provides an excellent guide to this emerging landscape. Another source for relevant online education is Tooling U-SME, a web-based, cloud-delivered, massively open online university that offers more than 500 online classes related to manufacturing technology, including for AI-related skills, breaking down the training into 9 functional areas and 60 competency models to identify gaps, define requirements, and provide specific guidance for individuals' AI skills development.[107]

POLICY RECOMMENDATIONS

National public policies can play an important role in helping individuals—and thus a country's broader workforce—develop digital skills, as the following section elaborates.

Allow Computer Science to Count Toward High School Science Requirements

High schools, whether in U.S. states or foreign countries, should both allow computer science to count as a math or science graduation requirement and remove barriers to students choosing whether to take computer science courses. This would also allow students to take computer science earlier in high school instead of waiting until after all their graduation requirements have been met. Students who have an aptitude for science, regardless of gender, are more likely to take computer science courses if they count toward graduation.

Teach Computer Science in All High Schools

U.S. states should prioritize making computer science available in every school. Several state and local governments, including Chicago's and New York City's, have begun to answer the call by mandating full access to computer science in their schools. Similarly, Texas requires computer science in schools, though implementation of this has been slow. In 2015, after its governor had made computer science education a core focus of his gubernatorial campaign, Arkansas passed a measure to put computer science in all schools, planning to have all primary students take computer science by the 2017–2018 school year, with computer science available at every high school.[108] In addition, Idaho, Alabama, Utah, and Washington have prioritized computer science education and are actively working to improve curricula and expand access. Virginia is now in the process of passing legislation that will make it the first state to make computer science a core academic requirement for all K-12 students.[109] However, these mandates are only possible and advisable if effective, certified teachers are available. Otherwise, the result will likely be low-quality substitutes for real computer science courses taught by teachers without computer expertise.

Colleges should allow computer science and statistics to count toward math requirements for admissions (many U.S. colleges require students to have taken four years of mathematics). Some schools do not allow statistics to qualify for this, and many do not allow computer science to qualify. As a result, many students do not have the "space," or "bandwidth," to take these courses in high school given both all the state-imposed requirements and the entry requirements set by colleges themselves.

Double the Number of STEM Charter Schools in the United States

There are approximately 100 STEM-focused high schools in America. Most of these public STEM high schools can provide a deep dive into computer science for interested students and have been proven to be effective in including minorities and students from socioeconomically disadvantaged areas in high-quality STEM education.[110] Doubling the number of STEM high schools will allow more students with a passion and deep ability to excel in computer sciences. Moreover, efforts should be made to ensure that all existing STEM-focused high schools provide a deep and rigorous curriculum in computer science.

Establish an Incentive Program for Universities to Expand Computer Science

As noted, U.S. universities still aren't producing sufficient numbers of computer science graduates. Schools—at both the high school and university levels—need to work on generating interest in computer science classes among a broader and more diverse group of students, improving the quality of computer science classes, and expanding the number of available seats in computer science classrooms.[111] Congress could create an incentive program (perhaps slightly increasing available federal research dollars) for universities that expand computer science course offerings and produce more computer science graduates.

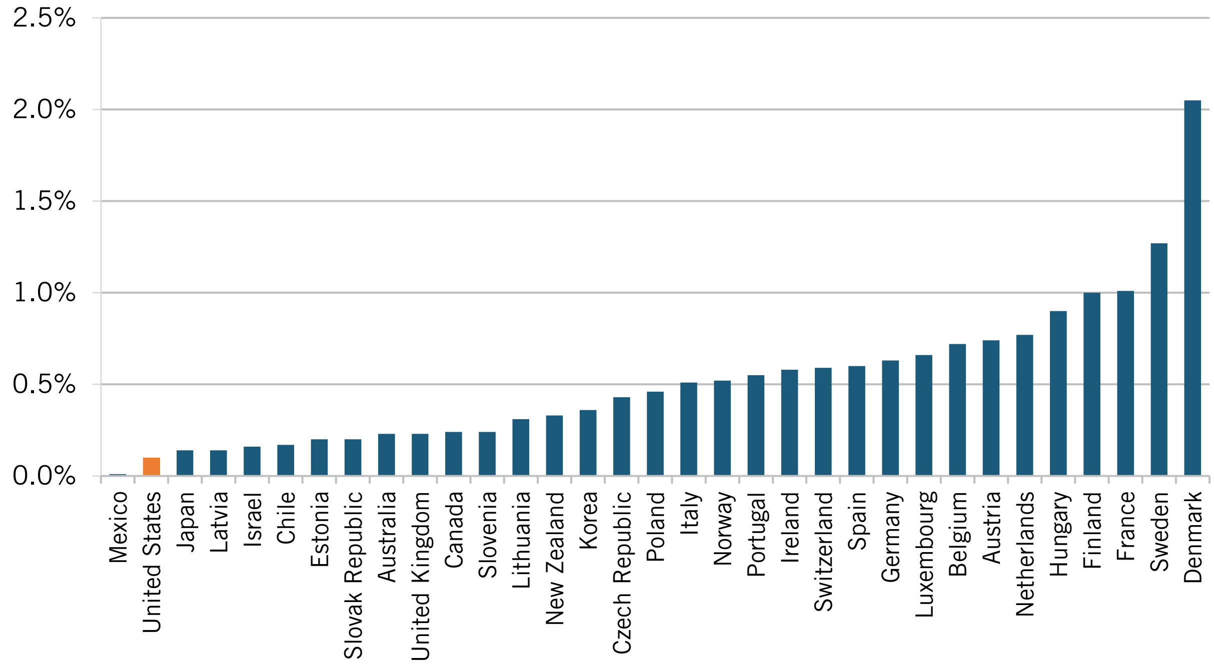
Invest in Cultivating AI Talent

Countries such as Canada, Finland, and the United Kingdom have launched initiatives to do just that—and the United States should adopt similar approaches. For example, Canada's AI strategy funds the creation of AI research institutes and programs to attract and retain AI talent in Canadian universities. Similarly, the United Kingdom's AI Sector Deal describes how the government will fund at least 1,000 AI Ph.D. students by 2025. Congress should fund and direct the National Science Foundation (NSF) to create a competitive AI fellowship program for at least 1,000 computer science students annually—and could go further by authorizing and funding an NSF program to provide competitive awards for up to 1,000 academic AI researchers for a period of five years. These awards would incentivize more AI researchers to stay in academia and help U.S. universities meet the demand for AI skills.[112]

Increase Federal Investment in Workforce Training and Reskilling Programs

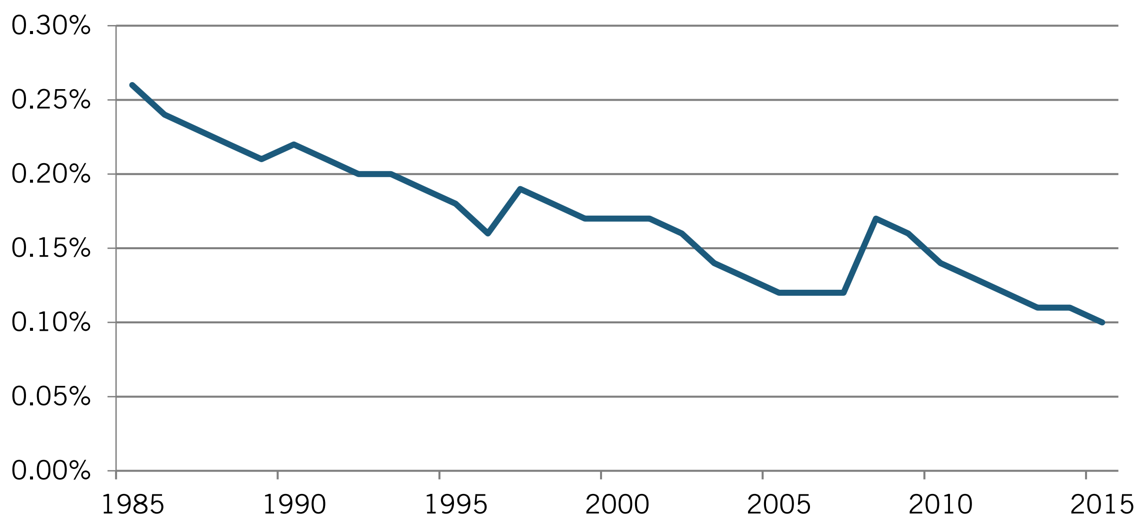
The United States significantly underinvests in workforce training programs, dedicating just 0.1 percent of GDP in active labor market programs compared with the OECD average of 0.6 percent of GDP, meaning America's OECD peers such as Austria and Germany invest six or more times more in their workforce training and support programs.[113] (See figure 19.) Such "active labor market policies" refer to government initiatives to help unemployed workers effectively transition back into the job market by addressing structural issues (rather than cyclical trends) caused by changes in the business model, such as recessions.[114] Moreover, the United States now invests less than half of what it did in such programs 30 years ago, as a share of GDP. (See figure 20.)

Figure 19: Public expenditure on active labor market programs (% of GDP)[115]



Note: Data for New Zealand and Estonia is from 2014. UK is 2011. All others are 2015.

Figure 20: U.S. public expenditure on active labor market programs as percent of GDP[116]



Expand Section 127 Tax Benefits for Employer-Provided Tuition Assistance

Section 127 of the federal tax code allows employers to provide employees up to $5,250 per year in tuition assistance; the employer deducts the cost of the benefit but the employee doesn't have to report it as income.[117] While it's an important benefit, Congress has not increased the eligible amount since 1996. Congress should increase Section 127 to at least $8,700 (per the rate of inflation since 1996) and index the amount to the annual rate of inflation going forward.[118] As the *2015 Economic Report of the President* finds, the proportion of workers that received employer-sponsored training dropped by 42 percent from 1996 to 2008.[119] Expanding the Section 127 benefit could help address this challenge, especially considering U.S. corporate investment in workforce training (including for digital skills) as a share of GDP fell by 30 percent from 1999 to 2015.[120]

Establish a Knowledge Tax Credit That Would Allow Firms to Take a Tax Credit for Expenditures on Both R&D and Workforce Training

While firms invest less in R&D than would be optimal from a societal or economic perspective—because the benefits spill over beyond their ability to capture all of them—the same can be said of their investments in workforce training. Thus, just as there's a compelling rationale to incentivize firms' investing in R&D through R&D tax credits, there is an incentive to encourage investment in workforce training. Accordingly, Congress should consider turning the research and experimentation credit into a knowledge tax credit by allowing qualified expenditures on both R&D and workforce training to be taken as a credit, and expanding the rate from 14 percent to at least 20 percent.[121]

CONCLUSION

As the modern economy becomes increasingly digitalized, a facility with digital skills becomes ever-more imperative for individuals wishing to make productive, value-adding contributions in their occupations. At the economy level, the broader quality of a workforce's digital skills base becomes a key determinant of enterprises' and industries' competitiveness and innovation capacity. A broad range of stakeholders—from individuals themselves to education systems across the K-12, community college, and university levels to businesses and nonprofits to government agencies—play important roles in developing a society's digital skills. Government policies can play catalytic roles in supporting funding for programs that teach digital skills and for getting the incentive environment right to stimulate corporate and individual investment in digital skills. The United States has clearly led the global digital revolution and certainly still has world-leading digital enterprises with highly skilled technologists in ICT fields. However, in terms of broader workforce digital skills across the entire economy, the United States is increasingly faltering at the very time when those skills are becoming ever-more important across an increasing range of occupations and industries, a phenomenon that bodes poorly for long-term U.S. competitiveness if such trends aren't quickly rectified. As such, the United States needs to redouble its efforts here, and recommit itself to being a world leader in workforce-level digital skills.

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The Information Technology and Innovation Foundation (ITIF) is an independent, nonprofit, nonpartisan research and educational institute focusing on the intersection of technological innovation and public policy. Recognized by its peers in the think tank community as the global center of excellence for science and technology policy, ITIF's mission is to formulate and promote policy solutions that accelerate innovation and boost productivity to spur growth, opportunity, and progress.

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